Annals of Microbiology, **57 (4)** 471-479 (2007)

Bio-conversion of organic wastes for their recycling in agriculture: an overview of perspectives and prospects

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Received 28 August 2007 / Accepted 24 September 2007

Abstract - Largely accessible organic wastes can be turned into valuable compost product for raising crops organically on one hand, and get them disposed off safely at the other end. Straight use of organic wastes has tribulations like transportation and handling, wider C:N ratio, high application rates, nutrient overloading, weed seeds, pathogens, and metal toxicities. Composting bestows a tactic for coping high volumes of organic wastes in environmentally sound and desirable manners. Composted materials are remarkably regarded for their ability to improve soil health and plant growth, and suppress pathogens and plant diseases. Currently several composting systems have become available; ranging from a crude and slow windrows method, to the most speedy and computer monitored in-vessel system. Scientific investigations of this biological cum chemical process have reached to molecular level. Value addition of compost through beneficial microorganisms, mineral materials and fertilisers is also being considered. The nature and composition of materials put into composting is imperative for its quality rationale. On the whole, principles and processes governing composting are not so straightforward that ordinary enterprises could develop efficient composting facilities for the treatment of organic wastes. In this scenario, accessibility of comprehensive information to the scientific community as well as environmental protection agencies is imperative. This review article brings together the current information necessary for effective composting of organic wastes from different origins with diversified characteristics under various situations. It also covers the schematic description of well known composting systems, and various factors controlling the process.

Key words: environmental pollution, composting, microorganisms, soil productivity, systems, additives.

INTRODUCTION

Municipalities, industries and agriculture farms are generating huge amounts of organic wastes. These wastes, in addition to disposal constraints are also posing a serious threat to the environment and human health, and toxicity to beneficial microflora in soil (Giuntini *et al.*, 2006). Notion of landfills for waste disposal has changed its dimension due to large quantities of waste generation, and reduced availability of dumping sites and environmental hazards. Similarly, incineration is expensive and causes air pollution. However, land application of organic wastes has emerged as an attractive and cost effective strategy. These wastes have been proved to supply plant nutrients and organic matter to the soil for crop production (Smith, 1996; Jilani *et al.*, 2007).

Direct application of raw organic wastes is inappropriate for land use due to their unknown composition for having pathogens, toxic compounds, weed seeds, heavy metals and foul odours. Kara and Asan (2007) reported that fungal community composition was influenced by the organic compounds entering soil from plant litter. Composting is considered the most appropriate option for addressing the constraints associated with organic solid waste materials for agricultural use (Goldstein, 1980; Wolkowski, 2003). Composting can be defined as the bio-conversion of organic wastes into an amorphous dark brown to black colloidal humus like substance under conditions of optimum temperature, moisture and aeration (Gaur and Singh, 1995). It is an economically attractive technique of waste disposal and recovery of valuable plant nutrients (Roger *et al.*, 1991). Using composted organic waste would partly solve the problems associated with organic wastes for their agricultural providence (Cáceres *et al.*, 2006). Composts provide plant nutrients, and improve soil biophysical properties, soil organic matter and crop yields (Reddy *et al.*, 2005).

Until a few decades back, composting was mostly left to nature on chance. Nevertheless, since World War II great efforts have been made to focus on the scientific processes occurring during the composting period. The concept of large-scale composting "Indore Process" was given by Sir Albert Howard, between the years 1924 to 1931 (Howard, 1943). The first full scale, refuse-composting facility in Europe was established in Netherlands in 1932. The

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process used was the "Van Maanen" process, which was modification of Indore method. This method appeared to be well suited for developing countries due to low technology utilisation and easily available equipments (Epstein *et al.,* 1976). During 1975, the USDA research team developed the "Aerated Static Pile Method". Breidenbach (1971) indicated that there were more than 30 composting systems in 1969. Currently, even more systems based on scientific principles are available around the world.

Composting is generally carried out by aerobic methods in the interest of rapidity and quality of the product. It is desirable for intensive crop production as well as for disposal of hugely accumulating wastes. Hence, some biological and mineral additives in composting are also given consideration. Quality composts can also be obtained in a short period of time by the use of microbial inocula as starter (Shin *et al.*, 1999; Baheri and Meysami, 2002). Studies by Lei and Gheynst (2000) revealed that inoculations could increase the microbial population, formulate beneficial microbial communities, improve microbiological quality and generate various desired enzymes; and thus enhance the conversion of organics and reduce odorous gas emissions. Hamdy (2005) confirmed the potentiality of *Rhizopus orizae* to utilise orange peels with high cellulolytic and pectinolytic activities.

In the followings is an overview of scientific developments regarding composting process, factors controlling waste decomposition, composting systems and necessary inputs for converting organic wastes in a valuable good quality product within an appropriate span. This also explores the potential areas of research on composting process under different situations with respect to time, space and climate.

COMPOSTING PROCESS

Composting is a biological process which converts heterogeneous organic wastes into humus like substances by mixed microbial population under controlled optimum conditions of moisture, temperature and aeration (Fig. 1). It is the aspect of control that separates composting from natural rotting or decomposition processes which occur in an open dump, sanitary landfill, or unmanaged waste pile (Roger *et al*., 1991). In composting, microorganisms convert organic materials such as manure, sludge, leaves, fruits, vegetables and food wastes into product like soil humus (Rynk, 1992; Reinikainen and Herranan, 1999). Through composting organic waste materials are decomposed and stabilised into a product that can be used as soil conditioner and/or organic fertiliser (Ahmad, 2007). Decomposers include bacteria, actinomycetes and fungi that are widespread in nature. These are indigenous to soil, dust, fruit and vegetable matter and wastes of all sorts, so special organisms are not required (Rodrigues, 1996). Controlled decomposition occurs as a result of activities of these naturally occurring microorganisms.

Composting can be considered as microbial farming, so they need energy, food, and habitat. These microorganisms require carbon as energy source and nitrogen to build proteins. Bacteria produce enzymes to break down complex carbohydrates into simpler forms (Hamdy, 2005), and use them as food. Composting process continues until the remaining nutrients are consumed by the last microorganisms and most of the carbon is converted into carbon dioxide and water (Rynk, 1992). The nutrients that become available during decomposition remain in the compost within the bodies of dead microorganisms and in humus.

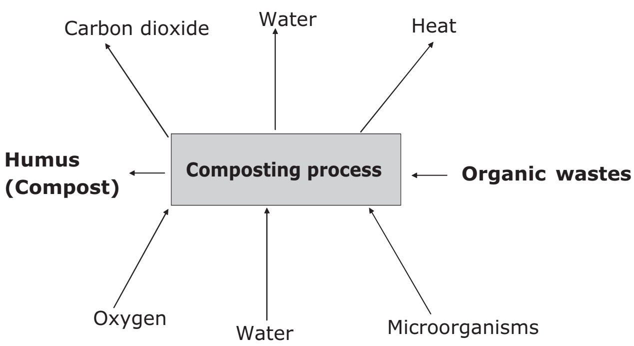

FIG. 1 - Inputs and outputs of the composting process.

COMPOSTABLE MATERIALS

Anything biodegradable and organic in nature can be composted. Unfortunately, not all decomposable materials are composted. According to an estimate by Barker (1997), 827 million tons of compostable materials are produced each year, largely by agriculture, municipalities, and industry. However, only 140 million tons, or 17 percent, of those are collected for composting.

Many agricultural wastes contain sufficient amount of organic materials for composting (Table 1). These include solid urban waste, food factory waste and other industrial by-products, sewage sludge, agricultural residues and

TABLE 1 - Suitability of different organic substrates for composting

Composting material	C:N	Suitability	References
Chicken manure, sewage sludge, alfalfa residues, cattle manure, food waste and farm yard manure	≤20:1	Most suitable due to their high nitrogen content	Tisdale *et al*. (1993); Hyvönen *et al*. (1996) Gaur (1997) Dinçer *et al*. (2003); Lekasi *et al*. (2003)
Fruit and vegetable wastes, grass cuttings and waste from food processing units	≤27:1	Moderately suitable	
Sawdust, coir waste, corn stover, wheat straw etc. including all crop residues	≤208:1	Less suitable	

domestic waste. Municipal solid waste, commonly called as trash or garbage, has been composted and applied to many crops, with improved yields and other benefits (Shiralipour *et al*., 1992; Stratton and Rechcigl, 1997). Coal bottom and fly ash, cement, kiln dust, biosolids, water treatment sludges, food processing by-products, animal and plant residues, by-products from metal smelting, paper and wood industries by-products, tannery sludges, textiles production by-products, rock dusts, chemical and drug production by-products have all been composted and land-applied (Stratton and Rechcigl, 1998).

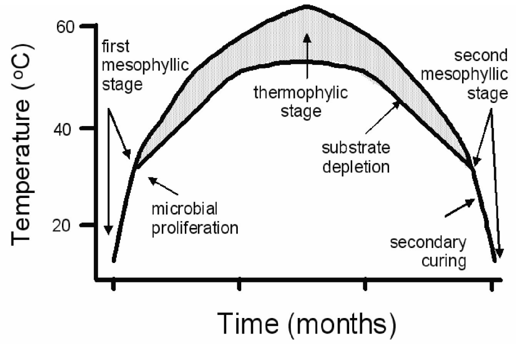

FIG. 2 - Different stages of composting process (Modified from Lekasi *et al.,* 2003).

STAGES OF COMPOSTING

The composting process is characterised by a period of rapid decomposition and temperature rise followed by cooler, slower decay of remaining organic substrates (Fig. 2). The rate of decomposition can be increased by stacking the materials in a pile however, taller stacks must be avoided to facilitate rapid decomposition and prevent the formation of unwanted anaerobic by-product. Temperatures vary in a compost pile with the outer layer having a lower temperature compared to the inner zone of high temperature. To ensure even decomposition and better aeration, periodic turning is necessary. Microbial populations change with temperature during the mesophilic (20-40 °C) and thermophilic stage (> 40 °C).

The mesophilic stage is preparatory state that initiates the decomposition process and brings the compost into temperature ranges that are suitable for thermophiles. This stage is achieved by readily available and easily decomposing compost substrate. Temperature rises rapidly from mesophilic stage to high levels up to 65 °C (thermophilic stage). The thermophilic stage is necessary to ensure stabilisation and pasteurisation of the compost, eliminating many harmful organisms. This stage may last for a number of days depending on how well oxygen is supplied to the pile and quality and quantity of the substrate. The compost pile temperatures fall back to mesophilic range and re-establishment of the mesophilic organisms occurs (Epstein, 1997; Lekasi *et al*., 2003).

FACTORS AFFECTING COMPOSTING

The composting process depends upon various factors like carbon : nutrients ratios, kinds and activity of microorganisms, water content, temperature, pH, aeration, particle size and nature of the material to be composted (Table 2). The details for each factor are given in the following.

Carbon : nutrient ratio

The ratio of carbon with other nutrients of the organic wastes is very critical in composting process. The composting process depends upon the action of microorganisms, which require a source of carbon to provide energy and a supply of nitrogen for cell proteins. Nitrogen is most important nutrient and there is smaller requirement for phosphorus and certain other elements. The C:N ratio of 25-35:1 is generally considered optimum (Gaur, 1997). A narrower C:N ratio (< 25) may lead to loss of N from compost through ammonia volatilisation. Wider C:N ratios (> 40) promote immobilisation of available N in the compost slowing the rate of decomposition. It has also been found that narrowing of C:N ratio can increase composting process tremendously (Mishra, 1992; Haug, 1993; Barker, 1997).

Enrichment of organic materials having wider C:N ratio such as cereal straw with N fertiliser hastens its decomposition (Banger *et al*., 1988). Therefore, enrichment of low quality residues with mineral N and P in the process of fortification can enhance decomposition.

Microorganisms

Composting is a dynamic process carried out by a rapid succession of mixed microbial populations. The main groups of microorganisms involved are bacteria, actinomycetes and fungi (Golueke, 1991). Although the total

TABLE 2 - Factors affecting the composting process

Factors	Best range	Comments	References
C:N ratio	25-35:1	Process proceeds rapidly with high efficiency of N assimilation	Gaur (1997)
Moisture	40-60%	Diffusion of soluble molecules and microbial enzymes	Willson (1989); Gaur (1997)
Aeration	10-30%	Aerobic decomposition is more rapid than anaerobic	Willson (1989); Gaur (1997)
Temperature	50-60 ºC	Most of the pathogenic microorganisms are killed	Gaur (1997)
pH	Normally not necessary	Organic wastes suitable for composting have a range of pH from 5-12	Willson (1989); Gaur (1997)
Particle size	10-50 mm	10 mm for agitated and forced aeration , 50 mm for natural aeration in heaps	Gaur (1997); Zia *et al*. (2003)

number of microorganisms does not change significantly during composting, the microbial diversity can vary during different phases of composting (Atkinson *et al*., 1996). The precise nature and number of microorganisms at each composting phase is dependent on the substrate and on the preceding succession (Crawford, 1983).

At the beginning of composting, mesophilic bacteria predominate but after the temperature increases to over 40 ºC thermophilic bacteria take over in the compost. When the temperature exceeds 60 ºC, microbial activity decreases dramatically but after the compost has cooled mesophilic bacteria again dominate (McKinlely and Vestal, 1985; Strom, 1985). Actinomycetes appear during the thermophilic phase as well as the cooling and maturation phase of composting, and can occasionally become so numerous that they are visible on the surface of the compost (Tuomela *et al*., 2000). The majority of fungi are mesophilic which grow between 5 ºC and 37 ºC with an optimum temperature of 25-30 ºC (Dix and Webster, 1995). However, in the compost environment thermophilic fungi are an important biodegradation agent.

Moisture

Moisture content is very important for composting and it may become the limiting factor if not monitored. Excess water interferes oxygen accessibility, while too little hinders diffusion of soluble molecules and microbial activity, slowing down the rate of composting. Moisture content of 40 to 60 percent has been found optimum for good composting process (Willson, 1989; Gaur, 1997). While a moist mixture is necessary to sustain the biological decomposition vital to the composting process, dry compost is easier to manipulate and store without causing a nuisance. Only after composting has been completed, drying could be considered as a necessary prerequisite for storage or sale (Roger *et al*., 1991).

Temperature

High temperature maintained during composting serves to promote efficiency and effectiveness of compost by accelerating the process and by destroying pathogenic microorganisms. High temperature of compost pile, in conjunction with satisfactory levels of other important composting factors, indicates the likelihood of successful composting. While low temperatures retard composting, and may even halt the process. Low temperatures are indicative of reduced microbial activity and could indicate a lack of oxygen or inadequate moisture conditions. The critical temperature, which limits composting, has yet to be defined (Roger *et al*., 1991). However, Gaur (1997) suggested that a temperature of 55 to 60 ºC should be maintained up to three days for efficient composting.

pH

No specific pH is required for composting process (Gaur, 1997) as different organic wastes suitable for composting have a range of pH from 5 to 12 (Willson, 1989). Metabolic activities affect the pH of compost under process. Deamination of protein rapidly increases the pH due to ammonia. Conversely, production of organic acids during the decomposition of carbohydrates and lipids decrease the pH. On average, pH of inputs is somewhat acidic while finished compost is neutral. Hernando *et al*. (1989) reported that compost products usually have a near to neutral or slightly alkaline pH with a high buffering capacity.

Aeration

Composting systems are distinguished on the basis of oxygen usage (aerobic vs. anaerobic). Aerobic decomposition, in contrast to anaerobic types, is quicker, progresses at higher temperatures, and does not produce foul odours. While anaerobic decomposition may be conducted with minimal operator attention and the operation may be sealed from the environment. However, the most modern composting operations attempt to maintain an aerobic environment (Roger *et al*., 1991). Mixing the compost pile at intervals aerates it, but it is often difficult to determine the exact periods to turn the pile. Aeration conducted in excess is usually not harmful to the composting process, except that an optimum temperature is harder to maintain and excessive evaporation may cause moisture to become a limiting factor. An oxygen level from 10 to 30% has been reported optimum by Willson (1989) and Gaur (1997).

Particles size

Particles size affects oxygen movement into the pile, as well as microbial and enzymatic access to the substrate. Smaller size particles of organic material increase the surface area available for microbial attack. However, very small particles pack tightly together; preventing movement of air into the composting heap and movement of carbon dioxide out of the heap. Large size particles reduce surface area for microbial attack which slows down or may stop composting process altogether (Zia *et al*., 2003).

Bulky organic materials should be chopped or shredded to reduce particle size to the range of 1-5 cm. On the other hand if too small, the organic materials should be mixed with a bulking agent like wood chips or tree bark. A particle size of 5 cm is appropriate for heaps employed to natural air flow, while 10 mm size is suitable for the composting systems having forced air supply (Gaur, 1997).

Nature of materials

Physical and chemical characteristics of the materials intended for composting directly affect the conditions like proper moisture, aeration and temperature. Important physical properties include particle size and moisture content, while the chemical characteristics are considered in terms of nutrient quality and quantity of organic residues. The ranges of elemental composition for some residues suitable for composting are shown in Table 1. Composting two or more materials together (co-composting) may accelerate the composting process, optimise C:N ratio, moisture content and particle size of the materials producing good quality soil amendment and conditioner (Stratton and Rechcigl, 1997). Optimum level of C:N ratio can be attained by combining nitrogen-poor and nitrogen-rich organic materials in proper ratio. Like, co-composting of woody plant materials and biosolids after mixing in proper ratio will result in a high quality end product (Stratton *et al*., 1995; Haug, 1993; Barker, 1997).

COMPOSTING SYSTEMS

Composting system can be as simple as using a pitchfork and people power, or as sophisticated as computer-controlled, state of the art machines will allow. Generally speaking, the better the system that is used, the higher is the quality of the compost. Currently three types of composting systems are the most widely used (Deportes *et al.*, 1995; Dinçer *et al.*, 1996; Anonymous, 1998) as described in the followings.

Windrows

This is the least sophisticated of the three which involves placing a mixture of organic waste materials into long, narrow piles approximately six feet high by twelve feet wide and as long as is necessary. The compost process is accelerated by frequent turning of the windrow with a front-end loader or custom designed machinery built for this purpose. Turning fluffs the pile and increases porosity of the mixture, which helps to improve the introduction of ambient air into the windrow.

Aerated static pile

This system involves supply of ambient air through mechanical means and requires no turning of the organic mixture once the pile is formed. By controlling air mechanically, this process allows the use of larger piles. For composting under this method, an air plenum is constructed and the organic mixture is placed in piles on top of the air plenum. Piles are built as high as the equipment allows, normally it is kept eight to twelve feet high. Aerated static piles can be constructed individually or in extended piles. Individual piles, constructed all at once, allow the composting to occur in batches. Extended piles consist of a series of cells created over the course of many days and stacked against each other to form one long rectangular pile. A temperature sensor placed within the pile works in conjunction with the blower to control temperature and oxygen concentration within the pile.

In-vessel composting

It involves confining the compost process to a variety of containers or vessels. Different in-vessel systems use a variety of methods to accelerate the composting process. These systems usually include provisions for aeration, mixing, temperature control, and containment of odours. In-vessel systems generally are the most costly of the three major technologies because of its high construction costs. Most of these are proprietary systems that also require greater operation and maintenance expenses and a higher skill level to operate.

Once a recipe has been established, the mixture will be incorporated into the compost technology chosen; either windrow, aerated static pile, or in-vessel composting. These technologies are designed to accelerate the decomposition process of organic materials. The management levels of these processes will either speed up or slow down the decomposition process, ultimately influencing the quality and cost of the product.

COMPOST MATURITY

The most suitable compost for agricultural use should be well cured and mature. The rates and timing of compost application hinge upon recognising differences in quality and maturity of the compost. At present, traditional tools as well as the sophisticated equipments are available for investigating maturity index, which can be adopted to the immediate needs of a small scale composting operation.

In general, maturity refers to: a) lack of toxins, such as acetic acid, phenols and ammonia; b) stabilisation of nutrients such as nitrate-N, phosphorus, iron or other elements which could otherwise pollute ground or surface waters; c) the absence of detrimental bacteria, fungi and noxious odours; and d) a noticeable reduction of heating upon rewetting (Stratton *et al*., 1995). Several discernible characteristics (Table 3) could be used to judge the maturity and quality of composts including texture, colour, smell and biological activity (Lekasi *et al*., 2003).

As compost texture is concerned, coarse materials become finer over time until a fine, loamy material is produced. Changes in the colour of the compost also represent its quality and maturity. The less decomposed material consists of a heterogeneous mixture of raw organic materials with different colours, giving a mottled appearance. As decomposition progresses, such material becomes more homogeneous, appearing as uniformly dark brown or black at maturity. While composting cattle manure, sewage sludge and some industrial wastes, the smell can indicate the stage of composting. Fresh animal manure and wastes have a strong smell of ammonia and putrefaction during the early stages of decomposition. Mature compost is expected to have only a slight ‘earthy’ and inoffensive smell.

Biological activity is another useful indicator of compost maturity. The presence of macrofauna in maturing compost, particularly earthworms and grubs, serves as an indicator of the stage of compost maturity. The fauna and flora of compost heaps changes with time, both increasing and decreasing with maturity depending on the group of organisms. The activity of earthworms might increase to a maximum and then decline towards maturity, while other soil fauna and fungi demonstrate peak activity at other times. Grubs (beetle larvae) are often in mature compost heaps. A clear understanding of changes of these different domains with respect to the composting process and stages can be used in combination to predict the quality and maturity of compost to a fairly accurate extent (Lekasi *et al*., 2003).

Several quick bioassays have been developed to check compost maturity. An easy method is plant tolerance test (Silva *et al*., 2007). Others prefer carbon dioxide release or oxygen uptake measurements (Graetz, 1996; Ahmad, 2007).

ENHANCING RATE AND QUALITY OF COMPOST

Getting compost ready speedily and concentrating it with nutrient elements is desirable for intensive crop production as well as disposal of continuously and hugely accumulated organic wastes. For this purpose some chemical and biological additives have been found beneficial by the scientists.

Chemical additives

These include mineral fertilisers and plant growth regulators (PGRs).

Mineral additives

Addition of mineral forms of nitrogen and phosphorus is conventionally recommended to lower the C:N and C:P ratios of composting material, where required, and to stimulate microbial activity. Additionally, these inputs cause substantial nutrient enrichment of the compost. There has been interest to produce P-enriched compost by the addition of some P sources such as rock phosphate (RP), basic

TABLE 3 - Physical and chemical characteristics of mature compost

Characteristics	Best range	Comments	References
pH	6.5–7.5	If below 5 or above 8 then it may be injurious to plants	Anthonis (1994); Bary *et al*. (2002)
Color	Dark brown to black		Lekasi *et al*. (2003); Zia *et al*. (2003)
Texture	Crumby	Larger particles change into finer ones	
Odour	Odourless	Mature compost (well decomposed) should have slight earthy smell	
Moisture	15-25%	Low moisture materials may be dusty	Anthonis (1994)
C: N ratio	10-15:1	Compost with high C/N ratio will reduce N availability to plants	Bary *et al*. (2002)
Organic matter	40-60%	Low values indicate compost mixed with soil. High values indicate fresh, undecomposed material	
Electrical conductivity	0-4 dS m^{-1}	Critical for greenhouse / potting mixes; less critical for farmland application	
Nitrogen	1-3%		Anthonis (1994)
Phosphorus	0.5-1%		
Potassium	1-1.5%		

slage and bone meal etc. Adding RP to composting material increases humic acid contents of the compost (Singh and Amberger, 1990).

Tiwari *et al*. (1989) reported that RP addition in wool waste resulted compost with C:N ratio of 20:1 after 10 weeks. Mishra (1992) prepared highly enriched compost from plant wastes by the addition of 25% Mussoorie RP. A good quality compost (with a C:N ratio of 12.3) from paddy straw was prepared within 8 to 10 weeks by the addition of 1 % RP (Gaur and Singh, 1995). Gowda *et al*. (1992) also observed enhanced content of N and P in the compost through amendment with RP.

Considerable amount of mineral N is lost by volatilisation during composting (Gaur and Singh, 1995). To overcome this problem, pyrite minerals have been tested as N-conserving additives. Using 1% urea N, 10 or 20% RP and 10% pyrite as conservative, Banger *et al*. (1989) made N and P enriched compost containing higher level of total N than usual and substantially high content of total P in the compost. Addition of NH_4NO_3 and NH_4Cl to the fermentation medium was found to improve the macerating potentiality due to an increase in enzyme levels (Hamdy, 2005).

Plant growth regulators

Biologically active substances or plant growth regulators (PGRs) are organic compounds, which have shown far-reaching impacts on growth of plants even at low concentration (Frankenberger and Arshad, 1995; Arshad and Frankenberger, 1998; Khalid *et al.*, 2006). It is likely that enrichment of composted material with nutrients and/or PGRs (kinetin, indole acetic acid and giberellic acid) can convert organic waste material into value-added organic fertiliser, for increasing crop yields. An organic fertiliser prepared by composting fruit and vegetable wastes and enriched with N and PGRs was found effective at as low as 300 kg ha^{-1} for improving growth and yield of wheat and maize (Ahmad *et al*., 2007; Zahir *et al*., 2007).

Biological additives

It includes addition of beneficial microbial inoculants and/or earthworms.

Microbial inoculants

The compost inoculants are known to speed up the decomposition process. They are cellulolytic and lignolytic microorganisms like *Trichuris spiralis*, *Paeciliomyces fusisporus*, *Trichoderma* and *Aspergillus* spp. Inoculation with cellulolytic fungi reduces the time needed for completion of the process and improves the quality of final product (Gaur, 1982). The nutrient status of sorghum stalk and wheat straw compost was improved after inoculation with *Aspergillus niger* and *Penicillium* spp. (Gaur and Sadasivam, 1993). The beneficial effect of cellulolytic fungi in composting of dairy farm wastes has also been reported (Tiwari, 1989). Singh and Sharma (2003) inoculated various kinds of wastes (mixed solid waste, municipal solid waste and horticultural waste) with different microflora viz. *Pleurotus sajor*, *Trichoderma harzianum* and *Azotobacter chroococcum* in different combinations. The waste was decomposed for different time periods and then subjected to subsequent composting for a fixed period of one month. The combination of *P. sajor*, *T. harzianum* and *A. chroococcum* produced the highest quality compost regarding nutrient contents. The efficient use of cellulolytic fungal culture (*Trichuris spiralis, Paecilomyces fusisporus, Trichoderma viride* and *Aspergillus* sp.) reduced the bulk of organic wastes by 5-10% and increased total N contents of the compost when added at the rate of 300 g t^{-1} material (Gaur and Singh, 1995).

An improvement in the nutrient content of compost by inoculation with *Azotobacter chroococum* and P-solubilizing microorganisms has also been reported (Sadasivam *et al*., 1981; Bhardwaj and Gaur, 1985). *Azotobacter* increases the N content and manurial value of the compost (Gowda *et al*., 1992; Yadav *et al*., 1992). Extensive studies by Gaur and Singh (1993) revealed these findings: using chopped straw, compost with 1.78% N and C:N ratio of 13.3 was produced with bioinoculant, as against 1.30% N and C:N ratio of 20 without bioinoculants; inoculation with *Azotobacter* and P-solubilizing microorganisms and addition of Mussoorie RP to sugarcane trash showed an increased P content, which was further increased by inoculating with cellulolytic fungi; inoculation of compost with *Azotobacter* and *Aspergillus awamori* increased the N contents of compost from 0.59 to 0.73% and increased available P from 87.3 to 140 ppm; and further enrichment with 5% RP and inoculation increased N content of compost by 30.5 %, available P by 125 % and C:N ratio dropped by 30 %.

Ahmad (2007) prepared an organic fertiliser by composting fruit and vegetable wastes and enriched it with N. It was used as a carrier for PGPR strain, *Pseudomonas fluorescens* biotype G (N3) containing ACC-deaminase to formulate a bio-fertiliser. This bio-organic fertiliser applied at 300 kg ha^{-1} was found to improve growth and nutrient uptake of maize. Studies by Diby *et al*. (2005) revealed the ability of *Pseudomonas fluorescens* strains to enhance nutrient mobilization in the rhizhosphere of black pepper, which resulted in enhanced plant vigour.

Earthworms

They feed on organic wastes, can ingest more than their body weight, and use only 5-10% of the feedstock for their growth. They excrete the mucus coated undigested matter as worm casts rich in macro and micro nutrients (Bhawalker and Bhawalker, 1993). These are also rich source of vitamins, enzymes, antibiotics, growth hormones and immobilised microflora (Kale *et al*., 1982; Bhawalker, 1991). Earthworms are often noticed in composting heaps, except in case of those materials which are offensive to their growth. They act as pulverizers of organic materials so as to promote microbial activity and facilitate aeration during composting. They have received considerable attention as inputs for composting and the practice is known as vermi-composting (Edwards *et al*., 1985).

A number of studies have revealed the usefulness of earthworms in processing organic wastes into compost (Tomati *et al*., 1983; Haimi and Huhta, 1987; Kale and Bano, 1994). It is an appropriate technique for the disposal of non-toxic solid and liquid organic wastes. It helps in cost effective and efficient recycling of animal wastes, agricultural residues and industrial wastes using low energy (Jambhekar, 1992). Usually, vermi-compost does not differ from wormless compost significantly in nutrient contents, but it differs only in its early processing and physical properties (Haimi and Huhta, 1987; Kale and Bano, 1994).

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